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CHAPTER 11

CABLE INSTALLATION

James D. Medek and William A. Thue

1. INTRODUCTION

Thomas A. Edison installed his earliest cables in New York City in 1882. The cables were placed in iron pipes in the factory and then were spliced together in the field every 20 feet in an egg-shaped splice casing. Other systems, such as by Brooks, Callender, and Crompton, were installed by 1885 where they also used short sections of iron conduit. American Bell Telephone Company installed the first flexible communication cables in 1882 and 1883 where cables were pulled into the conduit in the field. "Pumplogs" were first used for water supply lines, but were used in 1883 in Washington, DC, for telegraph cables. Tree logs were hollowed out, the exterior was trimmed to make them square, and the entire log was treated with creosote. These became the conduits of choice! So began the duct and manhole systems with the need to pull cables.

The *Underground Systems Reference Book* [11-1] of 1931 stated that "It is necessary to inquire into the harmful effects of the pulling stress on the cable insulation. The conclusion that has been reached, based on tests and experience, is that satisfactory operation of the cable is assured, provided that it has suffered no mechanical injury." It was recommended that a coefficient of friction between 0.40 and 0.75 should be used and that the total tension should be limited to 10,000 pounds. Little other advice was offered.

Significant advances were made in the understanding of cable pulling calculations with the 1949 paper by Buller [11-2] and the 1953 work of Rifenberg [11-3]. These papers provide the basic data for making cable pulls in all situations encountered in the field. They provide excellent quantitative data when used to calculate pulling tensions.

Even in the 1957 version of the *Underground Systems Reference Book* [11-4], there was little additional guidance given for such an important consideration as sidewall bearing pressure for distribution type cables. It was generally felt that 100 pounds per foot was acceptable. Later this was increased to 300 pounds per foot with no test work to support that value. Experience was still relied upon and 300 pounds met that criteria. A 400 pound per foot value was given for pipe type

cables.

Since the runs were relatively straight and short, this didn't pose a problem until the 1970s. Nuclear power plants had long pulls, many bends, and large cables. Many pulls exceeded that comfortable level established over the years.

Pipe-type cable systems pointed the way to the importance of accurate tension calculations. Here the avoidance of a splice could impact the cost of the system very significantly. Rifenburg's work [11-3] included all the necessary options, but the allowable sidewall bearing pressure needed to be evaluated since the somewhat arbitrary value of 400 pounds had not actually been tested in a laboratory environment. The understanding of the need for such information led to the project for "Increasing Pipe Cable Section Lengths," EPRI Final Report EL-2847, March 1983 [11-5].

A significant increase in understanding about cable pulls was reached with the completion of EPRI Final Report, EL-3333, "Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables," February 1984 [11-6]. A discussion of the results of these and other test work will be described below.

2. DISCUSSION OF CABLE PULLS

Cable manufacturers have handbooks in print that describe methods of making safe cable pulls and for making the necessary calculations of pulling tensions. Pull programs are available from suppliers of cable pulling compounds. Cable pull programs are available from EPRI [11-7]. There are many cable manufacturers, utilities, architect-engineering firms, and pulling equipment companies that also have programs.

An entirely new group of cable pulling compounds have become available since the EPRI project. They are able to achieve the very low coefficients of friction that their literature suggests -- generally these lower values are for the higher sidewall bearing pressures that are found in the field and in the newer test procedures.

2.1 Maximum Allowable Tension on Conductors

The maximum allowable tension on cable conductors that should be used during pulls must be based on experience as well as good engineering. Factors that have an impact on the value include type of metal, temper, and factors of safety. The limits have been set based on only the central conductor of the cable or cables. This quickly establishes one of the safety factors, because all of the components of a cable provide some mechanical strength.

One obvious limit is to consider the mechanical stress level at which the conductor will permanently deform/stretch. Upper limits have generally been set well below the elongation value of the conductor metal. The classic approach has been to use the values shown in Table 11-1, but the spread in values shown below represent present-day data from suppliers. Even higher values have been recommended and published by AEIC [11-7].

Table 11-1
Maximum Allowable Pulling Tension on Conductors

Metal	Temper	Pounds per cmil
Copper	Soft (annealed)	0.008
Aluminum	Hard	0.008
Aluminum	¾ Hard	0.006 to 0.008
Aluminum	½ Hard	0.003 to 0.004
Aluminum	Soft	0.002 to 0.004

2.2 Pulling Tension Calculations

The concept of the significant factors in a cable pull can be appreciated by looking at the equation for pulling a single cable in a straight, horizontal duct. The basic equation is:

$$T = W \times L \times f \quad (11.1)$$

where

- T = Tension in pounds
- W = Weight of one foot of cable in pounds
- L = Length of pull in feet
- f = Coefficient of friction for the particular duct material and outer layer of the cable.

It is obvious that the weight of the cable and the length of the pull can be determined with great accuracy. The one thing that varies tremendously is the value of the coefficient of friction -- it can vary from 0.05 to 1.0. In test conditions, values as high as 1.2 have been recorded! Even when the materials used in the duct and jacket are known, the type and amount of lubricant can be an important factor in this variation.

The significance of this is that the accuracy of the calculation can't come out to six decimal places even if you have a calculator or computer with that many places! It is also not wise to argue whether one method of tension calculation

can attain an accuracy of one percent better than another when one considers the probable inaccuracy of the coefficient of friction.

2.3 Coefficient of Friction

Since this is a significant variable in all calculations, let's look at this early in the discussion of cable pulling. What do we mean by "coefficient of friction?" Historically the test apparatus for friction determination consisted of a section of duct that was cut longitudinally in half. The open duct was mounted on an inclined plane. A short sample of cable was placed near the top end and the angle of incline was increased until the cable started to move as the result of gravity. Using the angle at which movement began, the static coefficient of friction was calculated. Generally the angle of incline could be decreased and the cable would maintain its slide. Using this second angle, the dynamic coefficient of friction was obtained.

As described above, many of the earlier publications suggested that the coefficient of friction that should be used varied from 0.40 to 1.0. This was, of course, very safe for most situations.

The EPRI project, [11-6], demonstrated that there were other important issues that needed to be established in making accurate determinations of the coefficient of friction such as the level of sidewall bearing pressure. This force is duplicated in present day test methods by applying a force that pushes the cable down on the conduit. The interesting fact is that this actually reduces the coefficient of friction in most instances! The quantity and type of lubricant are important. Too much lubricant can increase the friction. A more viscous lubricant should be used with heavier cables, etc.

2.4 Sidewall Bearing Pressure (SWBP)

When one or more cables are pulled around a bend or sheaves, the tension on the cable produces a force that tends to flatten the cable against the surface. This force is expressed in terms of the tension out of the bend in pounds divided by the bend radius in feet.

$$SWBP = T_o / R \quad (11.2)$$

where

$SWBP$	=	Force in pounds per foot
T_o	=	Tension coming out of the bend in pounds
R	=	Radius of the inside of the bend in feet

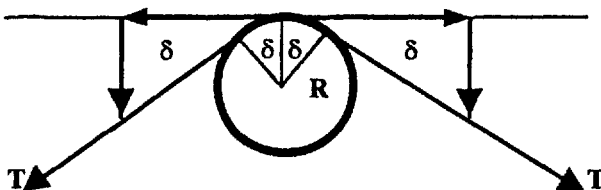
SWBP is not truly a unit of pressure, but rather a unit of force for a unit of length. In the case of a smooth set of sheaves or bend, the unit is the entire

length of contact. However, any irregularity, such as a bump on the surface, or a small radius sheave with limited bearing surface (even though it may be part of a multi-sheave arrangement), reduces the effective bearing surface length. This must be taken into account in the calculation to prevent damage to the cable.

For multiple cables in a duct, the matter is complicated because of the fact that the sidewall bearing pressure is not equally divided among the cables. This situation is taken into account by using the weight correction factor that will be discussed later in this chapter.

Figure 11-1 shows the mathematical derivation for a horizontal bend of one cable -- ignoring the weight of the cable. As the angle approaches zero, the force between the cable and the bend approaches unity.

Figure 11-1
Pulling Forces in Horizontal Bend



$$\text{The force per unit length} = \frac{2 T \sin \delta}{2 R \delta} \quad (11.3)$$

where $\sin \delta = \delta$ for small angles

$$\text{and sidewall pressure, } T/R = \frac{2 T \sin \delta}{2 R \delta} \quad (11.4)$$

The T / R ratio is independent of the angular change of direction produced by the bend. It depends entirely on the tension out of the bend and the bend radius with the effective bend radius taken as the inside of the bend. Increasing the radius of the bend obviously decreases the SWBP.

Sidewall bearing pressure limits that have been used historically are shown in Table 11-2. As with maximum pulling tension values, AEIC [11-7] has published limits that exceed the values shown in this table.

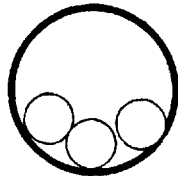
Table 11-2
Sidewall Bearing Pressure Limits

Cable Type	SWBP in Pounds per Foot
Instrumentation	100
600 V non-shielded control	300
600 V power	500
5 to 15 kV shielded power	500
25 to 46 kV power	300
Interlocked Armored	300
Pipe-type	1,000

2.5 Pulling Multiple Cables in a Duct or Conduit

2.5.1 Cradled Configuration. A frequent requirement is to pull three cables into one duct. This brings the relative diameters of the cables into play with the inner diameter of the duct. If the cables are relatively small as compared with the duct diameter, the cables are said to be “cradled.”

Figure 11-2
Cradled Cables



The outer two cables push in on the center cable, making it seem to be heavier than it actually is.

The pulling calculation handles this by using a “weight correction factor” that increases the apparent weight of that center cable.

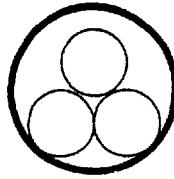
The sidewall bearing pressure (SWBP) on the center cable in Figure 11-2 is influenced by the other two cables. The effective SWBP for the cradled configuration may be calculated from:

$$SWBP = [(3 W_C - 2) / 3] T_O / R \quad (11.5)$$

See equations 11.2 and 11.7 for definitions of terms.

2.5.2 Triangular Configuration. When the diameter of each of the three cables is closer to one-third that of the inner diameter of the duct, the situation is known as a “triangular” configuration.

Figure 11-3
Triangular Arrangement



In this situation, the top cable is riding on the two lower cables without touching the duct wall.

The effect of this is that the one cable effectively increases the weight of the two lower cables, but does not function as a longitudinal tension member. This means that one must use the cross-sectional area of only two of the cables in the maximum allowable tension determination in this example, not three cables.

The sidewall bearing pressure on the two lower cables in Figure 11-3 is influenced by the upper cable. The effective SWBP for the triangular configuration may be calculated from:

$$SWBP = W_C T_O / 2R \quad (11.6)$$

The units are defined in Equations 11.2 and 11.7.

2.5.3 Weight Correction Factor. When two or more cables are installed in a duct or conduit, the sum of the forces developed between the cables and the conduit is greater than the sum of the cable weights.

Weight correction factor is therefore defined as:

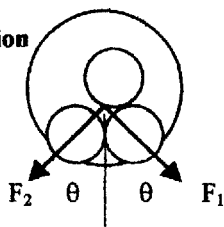
$$W_C = \Sigma F / \Sigma W \quad (11.7)$$

where

W_C	= Weight correction factor (also merely "c")
ΣF	= Force between cable and conduit, usually in pounds
ΣW	= Weight of the cable with same units as above

The mechanism for this relationship is shown in Figure 11-4 as:

Figure 11-4
Weight Correction



For the typical case of three cables of equal diameter and weights in a conduit of given size, the weight correction factor is higher for the cradled configuration than the triangular configuration.

Table 11-3
Weight Correction Factors

Configuration of Three Cables	Weight Correction Factor
Triangular	1.222
Cradled	1.441

It is always safer to anticipate the cradled configuration unless the cables are triplexed or if the clearance is near the 0.5 inch minimum.

The equations for calculating the weight correction factor are:

$$\text{Cradled:} \quad W_C = 1 + 4/3 (d/D - d)^2 \quad (11.8)$$

$$\text{Triangular:} \quad W_C = \frac{1}{1 - [(d/D - d)^2]^{1/2}} \quad (11.9)$$

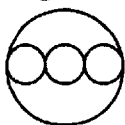
where

D = Diameter of inside of conduit

d = Diameter of each cable

2.5.4 Jamming of Cables. When the diameter of each cable is about one-third the inner diameter of the duct, a situation may occur where the cables may jam against the inside of the conduit. This generally occurs when the cables go around a bend or a series of bends. The "center" cable may try to pass between the outer two cables. When the sum of the diameters of the three cables is just slightly larger than the inner diameter of the duct, jamming can occur. Jamming increases the pulling tension many fold and can result in damaging the cable or even pulling cables in two, breaking pull irons in manholes, etc.

Figure 11-5
Cable Jamming



The condition that causes jamming for
three cables in a conduit.

The “jam ratio” of the cables in this duct needs to be evaluated. The equation for finding the jam ratio of three cables in a duct may be determined by:

$$\text{Jam Ratio} = 1.05 \times D_d / D_c \quad (11.10)$$

where D_d = Inside diameter of the duct or conduit
 D_c = Outer diameter of each of the three cables

The factor of 1.05 has been used to account for the probable ovality of the conduit in a bend and to account for the cable having a slightly different diameter at any point. If precise dimensions are known, this 5% factor can be eliminated.

Where the jam ratio falls between 2.6 and 3.2, jamming is probable if there are bends in the run and unless other precautions are taken. To avoid any problems with jamming, it is wise to avoid pulls where the ratio is between 2.6 and 3.2.

How can jamming be avoided even though the calculation shows that the ratio indicates a significant probability of jamming? There are several solutions, some of which are obviously possible during the planning stages and some that are possible during the installation stage.

- ☐ Use a different size of cable or conduit to change the ratio.
- ☐ Have the cable triplexed (twisted together) at the factory.
- ☐ Tie the cables together in the field with straps.
- ☐ Use precautions at the feed point to keep a triangular configuration and allow no crossovers.

The National Electric Code, ANSI C-1, requires that the total fill of a conduit be 40% or less for three cables in a conduit. This means that the cross-sectional area of all three of the cables cannot be more than 40% of the cross-sectional area of the conduit. Unfortunately, for 40% fill, the jam ratio is 2.74, which is in the lower danger ratio. An example of this situation is when three 1.095 inch diameter cables are installed in a conduit with an inside diameter of exactly 3.0 inches. (The actual inside diameter of a nominal 3 inch conduit is 3.068 inches!)

If the designer tries to reduce the fill to say 38% to stay safely within the 40% limit, the jam ratio gets worse – 2.81.

Utility practices generally are not governed by the NEC, hence clearance limits are not based on percent fill. Utility practice considers that 0.5 inches of clearance is satisfactory for general pulls. Clearances as small as 0.25 inches have been successfully made when good engineering practices and careful field supervision are employed [11-7].

To complete this discussion of jam ratio, it is important to know that jamming can occur when more than three cables are installed in a conduit. A modification of the equation is necessary as shown:

$$\frac{3D}{n_1 d_1 + n_2 d_2 + n_3 d_3 + n_4 d_4 + \dots} \quad (11.11)$$

where

$$\begin{aligned} D &= \text{Conduit inner diameter (ID)} \\ n_1, n_2, n_3, &= \text{number of cables of diameter 1, 2, 3, etc.} \\ d_1, d_2, d_3, &= \text{diameters of cables in groups 1, 2, 3, etc.} \end{aligned}$$

Theoretically any combination of cable diameters that fall in the critical zone can jam. Field experience has shown that the probability of jamming decreases as the number of cables increases.

2.5.5 Clearance. Another consideration before cables are placed in a conduit is the amount of clearance between the cable or cables and the inside of the conduit. This may be quickly seen in the example of the three cables in a triangular configuration in Figure 11-1. The distance from the top cable to the inside “top” of the conduit is defined as the clearance.

3. PULLING CALCULATIONS

The previous sections have presented some of the fundamentals of pulling cables. Now let's see how those factors, plus a few more, come together when we actually calculate the tension on a cable or cables that are to be installed.

3.1 Tension Out of a Horizontal Bend

Bends in cable runs are a fact of life. The important point is that the friction and sidewall bearing pressure around that bend increase the tension coming out of the bend in respect to the tension on the cable coming into the bend.

$$T_O = T_{IN} e^{f\alpha} \quad (11.12)$$

where

- T_O = Tension going out of the bend
- T_{IN} = Tension coming into the bend
- c = Weight correction factor
- f = Coefficient of friction
- a = Angular change of direction in radians

This is a simplified equation that ignores the weight of the cable. It is sufficiently accurate where the incoming tension at the bend is equal to or greater than ten times the product of the cable weight per foot times the bend radius expressed in feet. The practical situation where T_{IN} is less than ten times the product of the weight and radius is where the cable is being fed at low tension into a large radius bend [11-8]. In such a case, the equation becomes:

$$T_O = T_{IN} \left[\frac{e^{cfa} + e^{-cfa}}{2} \right] + \left[(T_{IN})^2 + (wr)^2 \right]^{1/2} \left[\frac{e^{cfa} - e^{-cfa}}{2} \right] \quad (11.13)$$

In order to fully appreciate the effect of the impact of the exponent of e , cfa , Table 11-4 shows the multiplier of the tension for various values of the exponent.

Table 11-4
Multiplier of Tension in Values for Various Exponents

cfa	45 Degree Bend	90 Degree Bend
0.1	1.08	1.17
0.2	1.17	1.37
0.3	1.27	1.60
0.4	1.48	2.19
0.5	1.60	2.56

It is essential to remember that the exponent of e has three terms: weight correction factor, coefficient of friction, and angle of deflection. Sometimes this exponent is shown only as two factors because of limitations of older computer programs. In order to make that workable when multiple cables are installed, it is necessary to multiply the selected coefficient of friction by the weight correction factor. If you therefore have a situation where three cables will be cradled, for instance, the cfa value (from Table 11-4) is 1.442 times the coefficient of friction. Putting this another way, if you consider the proper coefficient of friction to be 0.2, and the cables will be in a cradled configuration, you must use a cfa value of 0.3. If there is only one cable, this means that you would use the 0.2 value of cfa for that same coefficient of friction since W_C for

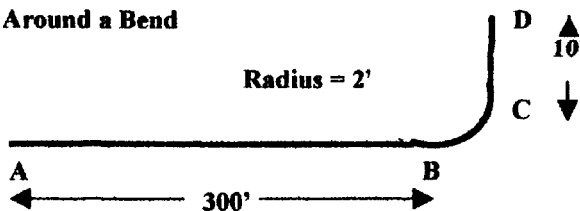
one cable is unity.

A large number of bends in a run can literally multiply the tension exponentially! This is one of the reasons that many installation practices keep the number of 90° bends to a maximum of three or four.

3.2 Which Direction to Pull?

There are always two possible directions that a cable can be pulled for any run -- just as a cable always has two ends. Let us go through the calculations of an example that has one bend so that we can see how the pulling tension can vary.

Figure 11-6
Pulling Around a Bend



Given: 1 x 1,000 kcmil copper cable
Weight of cable = 6 pounds per foot
Coefficient of friction = 0.5

Pulling from A to D:

$$\begin{aligned}\text{Tension at A} &= 0 \\ \text{Tension at B} &= 300 \times 6 \times 0.5 = 900 \text{ pounds} \\ e^{f\theta} &= e^{1 \times 0.5 \times 1.5708} = 2.713^{0.7854} = 2.19 \\ \text{Tension at C} &= 900 \times 2.19 = 1,971 \text{ pounds} \\ \text{Tension at D} &= -10 \times 6 \times 0.5 + 1,971 = 30 + 1,971 = 2,001\end{aligned}$$

This exceeds the long established 1,000 pound limit for a pulling grip, so this must be pulled with a pulling eye on the conductor. The established limit for a 1,000 kcmil copper conductor is based on the conductor kcmils multiplied by 0.008, or 8,000 pounds.

The maximum allowable tension coming out of the bend at point C results in a sidewall bearing pressure of $1,971 / 2$, or 985.5 pounds per foot which is above the value generally agreed to by the manufacturers.

Pulling from D to A:

Tension at D = 0

Tension at C = $10 \times 6 \times 0.5 = 30$ pounds

$e^{cfa} = e^{1 \times 0.5 \times 1.5708} = 2.713^{0.7854} = 2.19$

Tension at B = $2.19 \times 30 = 65.7$ pounds

Tension at A = $300 \times 6 \times 0.5 + 65.7 = 965.7$ pounds

This is satisfactory in all respects. The total tension does not exceed 1,000 pounds and the tension coming out of the bend is well below accepted levels. A cable grip may be used to pull the cable from D to A.

From this example, it can be seen that it is always preferable to set up the reel as close to the bend as possible.

4. CABLE INSTALLATION RESEARCH

Pipe type cable pulling was addressed by EPRI in Final Report EL-2847, March 1983, entitled "Increasing Pipe Cable Section Lengths" [11-5]. Sidewall bearing pressures of up to 1,000 pounds per foot were recommended.

The fact that the suggested values for pulling tension and related considerations of extruded distribution cables had developed only from an understanding of past successful pulls made it seem reasonable to look at extruded dielectric cables using laboratory and field generated data. EPRI undertook Research Project 1519 in the late 1970s. The work was published as Final Report EL 3333 [11-6] in March 1983. Additional insight into pulling considerations was accomplished through the publication of AEIC G5-90 [11-7], *Underground Extruded Power Cable Pulling Guide*, in May 1990.

The values of sidewall bearing pressure, allowable maximum tension on the conductors, and maximum allowable tension on a pulling basket, are much less conservative than the level generally accepted by cable manufacturers.

Since there are obvious advantages for a utility to make longer pulls based on this data, a good deal of caution and education is necessary.

4.1 Research Results

Before reviewing the results, a few words of caution are needed. Field conditions are seldom ideal. The actual installation may not go as smoothly as was planned. For instance, when one believes that the cable may be pulled in one continuous motion, the actual pull may be made in a series of starts and

stops. This alters the coefficient of friction because of the unplanned start, with the cable probably already far into the duct. When one anticipates excellent lubrication, the amount of lubrication may be more or even less than that planned. Therefore,

- **Don't blindly use these values to their upper limits.**
- **Be conservative.**
- **Follow the cable manufacturer's recommendations.**

The most dramatic findings of this research project over previously accepted values were:

- Pulling tension on both copper and aluminum conductors was about 50% greater than older limits.
- Allowable sidewall bearing pressure was as much as 200% greater than previously recommended.
- Coefficient of friction was about 50% lower -- with values as low as 0.05.
- Basket grips could be used to pull 10 times (or more) the force previously recommended as long as tension limits on the conductor are not exceeded.

5. REFERENCES

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